Behaviour of Fly Ash based Geopolymer Concrete

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Abstract— It is a well-known fact that cement production depletes significant amount of natural resources and releases large volume of CO_2.Cement production is also highly energy intensive after steel and aluminum. On the other hand coal burning power generation plants produce huge quantities of fly ash. Most of the fly ash is considered as waste and dumped in landfills. In order to address the issues mentioned above it essential that order forms binders must be developed to make concrete. The geopolymer technology offers an attractive solution to address the problem. The present work embraces the concept of geopolymer to make fly ash based geopolymer concrete.

Key words: Flyash, Steel, Aluminium, Landfills, Geopolymers

I. Introduction

A. Back Ground

Concrete is one of the most widely used construction materials. It is usually associated with Portland cement as the main component for making concrete. The demand for concrete as a construction material is on the increase. It is estimated that production of cement will increase from about 1.5 billion tons in 1995 to 2.2 billion tons in 2010 (Malhotra 1999). The climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases such as carbon dioxide (CO_2), to the atmosphere by human activities. Among the greenhouse gases CO_2 contributes about 65% of global warming (McCaughey, 2002).

1) Effect of cement on atmosphere

The cement industry held responsible for some of the CO_2 emissions, because the production of one turn of Portland cement emits approximately one ton of CO_2 in to the atmosphere (Davidovits, 1994 McCaughey, 2002).

B. Past Research

In Geopolymer the polymerization process involves a chemical reaction under highly alkaline conditions on Al-Si minerals yielding Si-O-Al-O bonds. The chemical composition of geopolymer similar to Zeolite, but shows an amorphous Micro-Structure. The Structural model of geopolymer material is still under investigation; hence the exact mechanism by which geopolymer setting and gardening occur May consists of dissolution, transportation or orientation and poly condensation and takes place through and exothermic process.

C. What is Geopolymer Concrete?

Davidovits (1988; 1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product material such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term 'Geopolymer' to represent these binders. Geopolymer are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous.

D. Why Geopolymer Came Into Existence

Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice husk and metakaoline and development of alternate binders to Portland cement.

Si/Al	Application
1	Bricks, ceramics, fire protection
2	Low CO_2 cements, concrete, radioactive & toxic waste encapsulation
3	Heat resistance composites, foundry equipment‘s, fiber glass composites
>3	Sealants for industry
20<Si/Al<35	Fire resistance and heat resistance fiber

Table 1: Applications of Geopolymer

E. Fly ash Based Geo Polymer Concrete

In this project, fly ash-based geo polymer is used as the binder, instead of Portland or other hydraulic cement paste. The fly ash based geo polymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geo polymer concrete, with or without the presence of admixtures. The manufacture of geo polymer concrete is carried out using the usual concrete technology methods.

As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, in geo polymer concrete. The silicon and the aluminum in the fly ash react with an alkaline liquid that is a combination of Sodium Silicate and Sodium Hydroxide solutions to form the geo polymer paste that binds the aggregates and other un-reacted materials.

F. Concrete and Environment

An important ingredient in the conventional concrete is the Portland cement. Actual production of Portland cement contributes 13.5 billion tons of carbon dioxide per year (1 ton of carbon dioxide for each ton of produced cement) which is equivalent to 7% of the total global emission of carbon dioxide to the atmosphere. Geo polymer is made out of waste materials like fly ash, therefore does not have an industry of it and does not contribute to carbon dioxide emissions. The Portland cement production process is one of the most energy consuming mass production processes. A mixture of powdered raw materials requires heating to over 1400^0 C to obtain cement powder, with its corresponding high use of fuels. Geo polymer, on the other hand, can be produced out of waste products like fly ash, or out of claimed kaolin (meta-kaolin) which consumes significantly less energy.

As we know cement is the backbone for global infrastructural development. It was estimated that 7% of the world‘s carbon dioxide is attributable to Portland cement industry. Because of the significant contribution to the environmental pollution & to the high consumption of natural resources like limestone etc., we can‘t go producing more and more cement.

G. Fresh Geopolymer and Manufacturing Process

Using meta kaolin as the source material, Teixeira-Pinto et al (2002) found that the fresh geo polymer mortar became very stiff and dry while mixing, and exhibited high viscosity and cohesive nature. They suggested that the forced mixer type should be used in mixing the geo polymer materials, instead of the gravity type mixer. To improve the workability, they suggested the use of admixtures to reduce the viscosity and cohesion. Metakaolin and ground blast furnace slag, they measured the setting time of the geo polymer material both at room and elevated temperature. They found that the initial setting time was very short for geo polymers cured at 60°C, in the range of 15 to 45 minutes.

H. Factors Affecting the Properties of Geo polymers

Silicon oxide(sio2) to aluminum oxide ratio (al_2o_3), Mixing time, Rest period, Ratio of alkaline liquid-to-fly ash, Concentration of Sodium Hydroxide (NaoH) Solution, Ratio of sodium silicate solution-to-sodium hydroxide solution, Curing temperature, Curing Time, Handling Time, Addition of Super plasticizer, Rest period prior to curing, Water Content of Mixture, Age of Concrete.

I. Geopolymer Properties

The Poisson‘s ratio of fly ash-based geopolymer concrete with compressive strength in the range of 40 to 90 MPa falls between 0.12 and 0.16. These values are similar to those of OPC concrete**.** Geopolymer possess high early strength, low shrinkage, freeze-thaw resistance, sulfate resistance, corrosion resistance, acid resistance, fire resistance, and no dangerous alkali-aggregate reaction.

J. Benefits of Geopolymer Concrete

- Cutting the world‘s carbon foot print.
- The price of fly ash is low.
- Better compressive strength.
  1) Fire proof.
  2) Low permeability.
  3) Eco-friendly.
  4) Excellent properties within both acid and salt environments.

II. LITERATURE REVIEW

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III. SCOPE AND OBJECTIVES

A. Scope of Work

In this project our main aim is to determine the

- Compressive Strength of geopolymer concrete.
- Split Tensile Strength of geopolymer concrete.
- Flexural strength of geopolymer concrete.
- By varying the curing duration and Molarities of Alkaline liquid changed the strength.

This present work consists of fly ash, alkaline liquids. Alkaline liquid to the fly ash ratio is 0.45 and also replacing cement by 100% of fly ash. The present work aims of determining the Compressive Strength, Split Tensile Strength, and flexural strength of geopolymer concrete at 24hrs, 48hrs and 96hrs by hot air oven curing at temperature 60 °C.

B. Objective of the present Study

The objective is to reduce the co2 emission while production of cement by replacing geopolymer concrete. Geopolymer technology not only contributes to the reduction of greenhouse gas emissions but also reduces disposal costs of industrial wastes.

IV. CONSTITUENTS OF GEOPOLYMER CONCRETE

A. Fly ash

In the present experimental work, Class F (Fly ash) (American Society for Testing and Materials 2001) dry fly ash obtained from the silos of Kothagudam thermal power station, Telangana State, which was used as the base material. ASTM Fly ash obtained from coal burning power station. Most of the fly ash available globally is formed as a by-product of anthracite and bituminous coal. All the coal burning power plants considered to be environmentally unfriendly.

Fly ash can be used to manufacture Geopolymer concrete when the Silica (Si) and Aluminum oxides constituted about 80% (by mass) with the Si-Al ratio of about 2. The content of iron oxide usually ranged from 10-20% (by mass) whereas the calcium oxide content was less than 5% (by mass). The carbon content of fly ash, as indicated by the loss on ignition by mass, was as low as less than 2%. The particle size distribution test revealed that 80% fly ash particles were smaller than 50µm. (Gourley,2003; Gourley and Johnson 2005, wallah and Rangan 2006; siddiqui2007). The reactivity of fly ash in Geopolymer has been studied by (Fernandez – Jimenez, et-al 2006b).

B. Coarse and Fine Aggregates

The aggregate grading curves currently used in concrete practice are applicable in case of geopolymer concrete (Hardjito and Rangan, 2005; Siddiqui, 2007). In the present study locally available aggregate were used. The fine aggregate was obtained from the sand dunes in uncrushed form. Coarse aggregates were obtained in crushed form and majority of the particles were of granite-type. Two different combinations of coarse aggregate were used in the present study. They are 20mm, 12.5mm aggregates were used. In total coarse aggregate 20 mm aggregates is 60%, 10 mm aggregates is 40%

C. Alkaline Liquids Used

1) Sodium Silicate

A combination of sodium silicate solution (Na_2SiO_3) and sodium hydroxide solution (NaOH) as alkaline liquid. It is recommended that the Alkaline liquid is prepared by mixing both the solution together at least 24hours prior to use. The sodium silicate is commercially available in different grades. The sodium silicate solution with SiO_2-to-Na_2O ratio by mass of approximately 2, i.e., SiO_2=30.62%, Na_2O=13.39% and water=44.01% by mass generally used. The sodium hydroxide with 97-98% purity, in flake or pellet form, is commercially available. The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in the range between 8 Molar to 16 Molar; however, 8 Molar solutions is adequate for most applications. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 8 molar consists of 8×40=320 grams of NaOH solids per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids were measured as 262 grams per kg of NaOH solution with a concentration of 8 Molar. Similarly, the mass of NaOH solids per kg of the solution for other concentrations was measured as, 12 Molar: 361 grams, 14 Molar: 404grams and 16 Molar: 444 grams.

Oxides	%
SiO_2	29.4
Na_2O	14.7
Water	55.9

Table 2: Chemical Composition of Sodium Silicate A53 (% by Mass)

2) Hodium Hydroxide

Sodium hydroxide, also known as caustic soda with the molecular formula NaoH is a caustic metallic base which is a white solid available in pellets, flakes, granules, and as a 50% saturated solution. Sodium hydroxide flakes were used in the experimental program.

Fig. 1: showing sodium hydroxide pellets

In the present study we have used a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions. The sodium hydroxide solids were either a technical grade in flakes form (3 mm), 98% purity, or a commercial grade in pellets form with 97% purity.

For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentration.

D. Super Plasticizers

To improve the workability of the fresh geo polymer concrete, a naphthalene Sulphonate super plasticizer, Conplast SP430 was used in the Experimental study work. Another type of super plasticizer, a poly carboxylic ether hyper plasticizer, under the brand name of Glenium 27, this type of super plasticizer was not used due to the cost. Super plasticizer should be within the limit 1.5 to 2.5% of fly ash content. Exceeding this limit compressive strength of the geo polymer concrete will be decreased.

V. Mix Proportions

A. General Mix Proportions of Geopolymer Concrete

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminum oxides in the fly ash reacts with alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, and other un-reacted materials together to form the geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregates occupy 75 to 80% of the mass of geopolymer concrete. This component of geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and the properties of the constituent materials that make the geopolymer paste. Experimental results (Hardjito and Rangan, 2005) have shown the following:

- Higher concentrations (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete.
- Higher the ratio of sodium silicate solution-to-sodium hydroxide solution ratio by mass, higher is the compressive strength of geopolymer concrete.
- The addition of naphthalene sulphonate based super plasticizer, up to approximately 4% of fly ash by mass, improves the workability of the fresh geopolymer concrete; however, there is a slight degradation in the compressive strength of hardened concrete when the super plasticizer dosage is greater than 2%.
- The slump value of the fresh geopolymer concrete increases when the water content of the mixture increases.
- As the H_2O-to-Na_2O molar ratio increases, the compressive strength of geopolymer concrete decreases.

B. Mixing, Casting and Compaction of Geopolymer Concrete

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of the Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry in 80 liter capacity pan mixer for about 3 minutes. The aggregates were prepared in saturated-surface- dry (SSD) condition.

The alkaline liquid was mixed with the super plasticizer and the extra water, if any. The liquid component of the mixture was then added to the dry materials and the mixing is continued usually for another 4 minutes. The fresh concrete could be handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete (Hardjito and Rangan, 2005; Wallah and Rangan, 2006; sumajouw and Rangan, 2006). Fresh fly ash-based geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test.

Fig. 2: After casting the geopolymer concrete specimens.

C. Curing of Geopolymer Concrete

Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the compressive strength of geopolymer concrete. The test specimens were 150x150mm cubes heat-cured at 60°C in an oven. The curing time varied from 4 hours to 96 hours (4 days). Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was rapid up to 24 hours of curing time; beyond 24 hours, the gain in strength is only moderate. Therefore, heat-curing time need not be more than 24 hours in practical applications.

Heat-curing can be achieved by either steam-curing or dry-curing. Test data show that the compressive strength of dry-cured geopolymer concrete is approximately 15% larger than that of steam-cured geopolymer concrete (Hardjito and Rangan, 2005). The required heat-curing regime can be manipulated to fit the needs of practical applications. In laboratory trials (Hardjito and Rangan, 2005), precast products were manufactured using geopolymer concrete; the design specifications required steam-curing at 60°C for 24 hours. In order to optimize the usage of formwork, the products were cast and steam-cured initially for about 4 hours. In fact, such a delay in the start of heat-curing substantially increased the compressive strength of geopolymer concrete (Hardjito and rangan,2005). This may be due to the geopolymerisation that occurs prior to the start of heat-curing. The temperature required for heat-curing can be as low as 30 degrees. In tropical climates; this range of temperature can be provided by the ambient conditions.

Fig. 3: Specimens curing in hot air oven.

VI. EXPERIMENTAL INVESTIGATION

A. Introduction

The Physical properties, chemical properties of materials have been study such as

– Gradation of fine aggregate and coarse aggregate.
– Bulk density of fine aggregate.
– % of void ratio and porosity of fine aggregate.
– Void ratio of fine aggregate.
– Specific gravities of all ingredient materials

B. Alkaline Liquid Properties

Alkaline liquid used in making geopolymer concrete is NaOH and sodium silicate (Na_2sio_3) to act as a binding nature between fine aggregate, coarse aggregate and fly ash the Alkaline solutions are mixed at least 24hrs prior to use

1) Sodium Hydroxide

NaOH used in preparing GPC are 8M, 12M, 14M, and 16M.

– Molecular wt: 40gm/mo
– Specific gravity: 2.1
– Appearance: White solid

2) Sodium Silicate

Sodium silicate used in preparing used in GPC is having

– Na_2o=13.39% and sio_2=30.39 (%by wt),
– Mole Ratio=2.36
– Weight Ratio=2.28
– Specific gravity=1.54.

C. Properties of Fine Aggregates

Sieve No	Sieve size	Weight retained (g)	% wt retained	Cu mm% of wt retained
1	4.75mm	10	10	2
2	2.36mm	50	60	12
3	1.18mm	50	110	22
4	600µ	95	205	41
5	300µ	175	380	76
6	150µ	85	465	93

Table 3: Fineness modulus of fine aggregates

Fineness modulus of fine aggregate = 2.46, Bulk density = 1.46g/cc, % of void ratio and porosity = 38%, Specific gravity = 2.37, void ratio = 0.62.

D. Properties of Coarse Aggregates

Sieve No	Width of Apertur e	Weight Retaine d (Kg)	% Wt. Retaine d	Cumm % of wt. retained	% pass ing
1	80mm	0	0	0	100
2	40mm	0	0	0	100
3	20mm	1.48	29.6	29.6	10.4
4	10mm	3.42	68.4	98	2
5	4.75m m	0.1	2	100	0
6	2.36mm	0	0	100	0
7	1.18mm	0	0	100	0
8	600µ	0	0	100	0
9	300µ	0	0	100	0
10	150µ	0	0	100	0

Table 4: Fineness Modulus of Coarse aggregates

Fineness modulus of coarse aggregate=7.27

E. Experimental Program

Mix Design ation	No of specimens								
	Cubes			Cylinders			Prisms		
	24 hrs	48 hrs	96 hrs	24 hrs	48 hrs	96 hrs	24 hrs	48 hrs	96 hrs

GPC 8M	3	3	3	3	3	3	3	3	3
GPC 12M	3	3	3	3	3	3	3	3	3
GPC 14M	3	3	3	3	3	3	3	3	3
GPC 16M	3	3	3	3	3	3	3	3	3
Total	12	12	12	12	12	12	12	12	12

Table 5: Scheme of work

Total no of specimens = 36+36+36 = 108

1) Adopted Mix Design

a) Note

Molarity = moles of solute / liter of solution

Fly ash ratio: 0.45

F. Design Stipulations

- Sodium silicate-to-sodium Hydroxide ratio: 2.5
- Assume density of aggregate as unit weight of concrete = 2400 kg/m^3
- Mass of combined aggregate= 75-80% (consider 75%) = 2400 x 0.75 = 1800 kg/m^3
- Now, mass of combined aggregate = 1800 kg/m^3
- Mass of fly ash and alkaline liquid= 24000 – 1800= 600 kg/m^3
- Let us take alkaline liquid to fly ash ratio as 0.45
- Now the mass of fly ash= 600/(1+0.45) = 413.79 kg/m^3
- Mass of alkaline liquid= 600 - 413.79 = 186.2 kg/m^3
- Let us consider the ratio of NaoH to Na_2Sio_3 as 2.5
- Now mass of NaoH solution = 186.2/ (1+2.5) = 53.20 kg/m^3
- Mass of Na_2Sio_3 solution= 186.20 – 53.20 = 132.99 kg/m^3
- Mass of Coarse aggregate = 70% of the combined aggregate = 1800 x 0.7 = 1260 kg/m^3
- Partition of Coarse Aggregate
- 20mm (60%) = 1260X0.6=756 kg/m^3
- 10mm (40%) = 1260X0.4=504 kg/m^3
- Mass of fine aggregate = 30% of the combined aggregate =1800X 0.3 = 540 kg/m^3

A. L	Binder	Fine Aggregate	Coarse Aggregate
186.2	413.79	540	1260

Mix Proportion = 1:1.3:3.0.4:0.45

G. Preparing NAOH Solution for One liter Distilled Water

Therefore,

- Weight of NaOH required for 8M. = 320 grams
- Weight of NaOH required for 12M. = 480 grams
- Weight of NaOH required for 14M. = 560 grams
- Weight of NaOH required for 16M. = 640grams
- Weight of Na_2SiO_3 = 2.5 x 665.9 = 1.664 liters

H. Workability

To improve the workability of low calcium fly ash based geo polymer concrete we added a naphthalene sulphonate super plasticizer (CONPLAST SP 430) of 4% of Binder content.

I. Rest Period

After casting, the specimens are rested for one day before going to curing process for better compressive strengths.

J. Curing

In this study the curing was carried out at a specified elevated temperature in an oven dry curing at the end of the curing period, the specimen were then removed from the moulds, and left to air dry in the room temperature before testing at a specified age. The temperature of curing in this study was kept at 60^{0}c

K. Detention Period

After the curing process, the cubes are taken out and cooled at room temperature for 6 day before test.

L. Compressive and Split Tensile Strength

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. When the limit of compressive strength is reached, materials are crushed. When a specimen of material is loaded in such a way that it extends it is said to be in tension. on the other hand if the material compresses and shortens it is said to be in compression.

Fig. 4: Geopolymer concrete cube before failure and after failure in compressive testing machine

Fig. 5: Geopolymer concrete Cylinder before failure and after failure (split tensile strength test)

VII. Discussions of Results

A. Compressive Strength Results

Molarity duration of curing	8M	12M	14M	16M
24hrs	20.26	21.8	23.54	31.82
48hrs	29.24	32.26	30.52	39.24
96hrs	23.18	25.28	26.16	33.13

Table 6: Compressive strength of geopolymer concrete of oven curing at 60ºC

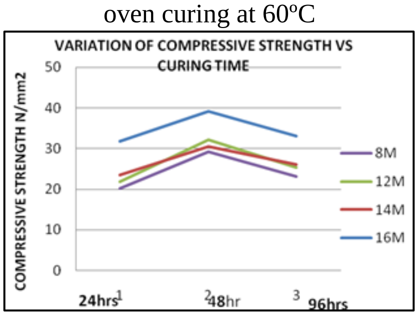

Fig. 6: Variation of Flexural Strength vs Curing Time

B. Split Tensile Strength Results

Morality/duration of curing	8M	12M	14M	16M
24hrs	2.28	3.05	3.63	3.88
48hrs	3.59	3.47	3.91	5.42
96hrs	3.12	3.37	3.77	4.99

Table 7: Split tensile strength of geopolymer concrete of oven curing at 60°C

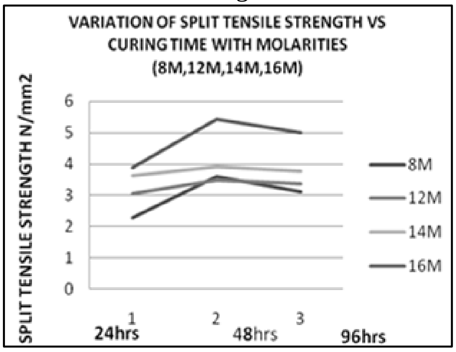

Fig. 7: variation of split tensile strength vs curing time with molarities

C. Flexural Strength Results

Morality/duration of curing	8M	12M	14M	16M
24hrs	4.75	5.8	5.78	6.69
48hrs	5.77	6.32	6.95	7.34
96hrs	4.95	5.44	6.29	6.93

Table 8: Flexural strength of geopolymer concrete of oven curing at 60°C

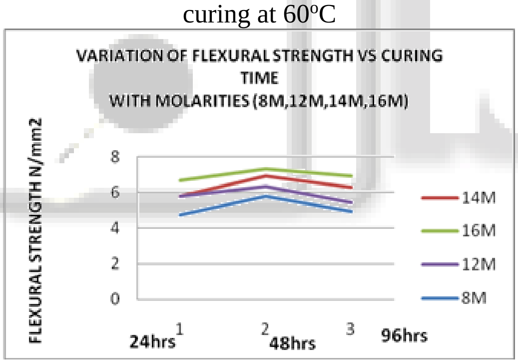

Fig. 8: Variation of Flexural Strength vs Curing Time

VIII. CONCLUSIONS

- As Molarity increases strength of Geopolymer concrete increases.
- The maximum Compressive strength of Geopolymer concrete is 39.24N/mm2 at 16M NaOH
- The maximum split tensile strength of Geopolymer concrete is 6.38 N/mm2 at 8M NaOH
- The maximum flexural strength of Geopolymer concrete is 7.34 N/mm2 at 8M NaOH
- As Age of curing time increases compressive strength, split tensile strength, flexural strength increases up to 48hrs and then it decreases from 96hrs.
- The compressive strength, Split tensile strength, flexural strength of Geopolymer concrete increases with the increase of molarity.
- It is observed that the grade of concrete for 28days obtained from the results of M30 grade which is a satisfactory target strength which comes under standard concrete.
- It is observed that the normal consistency does not depends upon the molarities of alkaline activator while the workability and final setting time decreases as the molarity of alkaline activator increases
- Geopolymer technology not only contributes to the reduction of greenhouse gas emissions but also reduces disposal costs of industrial wastes.
- Geopolymer technology encourages recycling of waste and finally it will be an important step towards sustainable concrete industry.
- The fly ash can be used to produce geopolymeric binder phase which can bind the aggregate systems consisting of sand and coarse aggregate to form geopolymer concrete (GPC). Therefore these concretes can be considered as eco-friendly materials.

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